PAPER

# Visuospatial abilities in cerebellar disorders

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**Background:** Cerebellar involvement in spatial data management has been suggested on experimental and clinical grounds.
**Objective:** To attempt a specific analysis of visuospatial abilities in a group of subjects with focal or atrophic cerebellar damage.
**Methods:** Visuospatial performance was tested using the spatial subtests of the WAIS, the Benton line orientation test, and two tests of mental rotation of objects—the Minnesota paper form board test (MIN) and the differential aptitude test (DAT).
**Results:** In the Benton line orientation test, a test of sensory analysis and elementary perception, no deficits were present in subjects with cerebellar damage. In MIN, which analyses the capacity to process bidimensional complex figures mentally, and in the DAT, which is based on mental folding and manipulation of tridimensional stimuli, subjects with cerebellar damage were impaired.
**Conclusions:** The results indicate that lesions of the cerebellar circuits affect visuospatial ability. The ability to rotate objects mentally is a possible functional substrate of the observed deficits. A comparison between visuospatial performance of subjects with focal right and left cerebellar lesions shows side differences in the characteristics of the visuospatial syndrome. Thus cerebellar influences on spatial cognition appear to act on multiple cognitive modules.

In the last decade, research on the role of the cerebellum in cognition has increased enormously. In particular, neuroimaging studies have provided evidence of cerebellar activation in various cognitive tasks. In spite of this, little is known about the functional mechanisms underlying the observed cerebellar activation. Early reports of cognitive deficits in patients with cerebellar lesions indicated that visuospatial ability was impaired with cerebellar damage.[1–4] These findings have received substantial support from recent neuroimaging data showing cerebellar activation during simple spatial tasks such as line bisection judgement[5] and during the mental rotation of objects.[6] Support for the role of the cerebellum in spatial cognition (for a definition of spatial cognition, see Halligan *et al* [7]) also derives from experimental findings that indicate the importance of the cerebellar circuits for acquisition of the procedural components required for spatial learning.[8 9]

Various different studies have investigated cognitive abilities, including visuospatial ability, in patients with cerebellar damage, both in adult life[1 10 11] and in childhood.[12] None of these studies focused specifically on visuospatial ability; however, hemineglect after a cerebellar lesion was reported recently in a single case study.[13]

In the present study we analysed visuospatial performances of subjects with cerebellar damage using the spatial subtests of the Wechsler adult intelligence scale, the Benton line orientation test, and two tests of mental rotation of objects—the Minnesota paper form board test and the differential aptitude test.

## METHODS

### Subjects

Thirty nine patients with cerebellar lesions and 41 normal subjects (control group) without a history of neurological or psychiatric illness, recruited from patients' relatives or volunteers, were enrolled in the study. Twelve patients were affected by focal cerebellar lesions on the left side (LCB group), 13 by focal cerebellar lesions on the right side (RCB group), and 14 by idiopathic cerebellar ataxia (ICA group) (table 1). Focal cerebellar lesions consisted of ischaemic or haemorrhagic stroke or surgical ablation because of arteriovenous malformations or tumours (table 1). The diagnosis of ICA was based on clinical indications of a purely cerebellar syndrome and on evidence from magnetic resonance imaging (MRI) of atrophic pathology restricted to the cerebellum.

All subjects were right handed and were unaware of the design and goals of the study. No patient included in the study had clinical or neuroradiological evidence of extracerebellar pathology at the time of testing. All patients underwent a neurological examination and their motor impairment was quantified by a modified version of the Appollonio cerebellar motor deficit scale,[14] which ranges from 0 (absence of any deficit) to 42 (presence of all deficits to the highest degree). All patients with cerebellar pathology were given verbal, spatial, and general intelligence tests to exclude the presence of global cognitive impairment. Some of these patients had participated in previous studies.[15–20]

The experimental procedures were approved by the ethics committees of Catholic University and the S Lucia Foundation. Written consent was obtained from each subject according to the Helsinki declaration.

### Tests

The Wechsler adult intelligence scale–revised (WAIS-R[21]) and three separate visuospatial tests—the Benton line orientation test (Benton), the revised Minnesota paper form board test (MIN), and the differential aptitude test (DAT)—were given to the subjects. As not all subjects were tested on all tasks (table 1), the number of subjects was different for each test.

**Abbreviations:** $C1_A$, control group for patients with idiopathic cerebellar ataxia; $C1_L$, control group for patients with left focal cerebellar lesions; $C1_R$, control group for patients with right focal cerebellar lesions; C2, control group for the spatial experiments; DAT, differential aptitude test; ICA, idiopathic cerebellar ataxia; MIN, Minnesota paper form board test; WAIS-R, Wechsler adult intelligence scale, revised

**Table 1** Patient characteristics

| Group | Patient | Age (years) | Educ (years) | Diagnosis | Motor score | WAIS | Benton | MIN | DAT |
|---|---|---|---|---|---|---|---|---|---|
| **LCB** | CD | 20 | 13 | Left ependymoma | 10 | ✗ | | | |
| (n=12) | CA | 48 | 12 | Left gangliocytoma | 3 | ✗ | ✗ | ✗ | ✗ |
| | FM | 29 | 12 | Left haemangioblastoma | 1 | ✗ | ✗ | ✗ | ✗ |
| | FP | 78 | 8 | Left haemorrhagic stroke | 7 | | ✗ | ✗ | ✗ |
| | LF | 34 | 18 | Left haemorrhagic stroke | 7 | ✗ | ✗ | ✗ | ✗ |
| | BC | 58 | 13 | Left PICA stroke | 8 | ✗ | | | |
| | BG | 81 | 5 | Left PICA stroke | 0 | | ✗ | ✗ | |
| | CO | 68 | 3 | Left PICA stroke | 7 | ✗ | ✗ | | |
| | DP | 67 | 5 | Left PICA stroke | 6 | ✗ | ✗ | ✗ | ✗ |
| | DG | 44 | 12 | Left SCA stroke | 1 | ✗ | ✗ | ✗ | ✗ |
| | DF | 42 | 11 | Left vascular malformation | 4 | ✗ | ✗ | ✗ | ✗ |
| | DR | 41 | 12 | Left vascular malformation | 3 | ✗ | ✗ | ✗ | ✗ |
| **RCB** | BS | 74 | 5 | Right AICA stroke | 7 | | ✗ | ✗ | |
| (n=13) | MA | 70 | 8 | Right AICA stroke | 19 | | ✗ | ✗ | ✗ |
| | DS | 42 | 18 | Right embolic stroke | 6 | ✗ | ✗ | ✗ | ✗ |
| | PM | 46 | 5 | Right ependymoma | 2 | ✗ | | | |
| | BA | 52 | 13 | Right haemorrhagic stroke | 8 | ✗ | | | |
| | MA | 46 | 13 | Right haemorrhagic stroke | 7 | ✗ | | | |
| | TA | 27 | 13 | Right haemorrhagic stroke | 11 | ✗ | | | |
| | CG | 52 | 5 | Right ischaemic stroke | 8 | ✗ | | | |
| | SL | 54 | 5 | Right ischaemic stroke | 3 | | | | ✗ |
| | AS | 32 | 13 | Right medulloblastoma | 3 | ✗ | ✗ | ✗ | ✗ |
| | CA | 60 | 5 | Right metastatic lesion | 1 | | ✗ | ✗ | ✗ |
| | LC | 68 | 8 | Right metastatic lesion | 9 | ✗ | | | |
| **ICA** | BE | 27 | 12 | Cerebellar atrophy | 12 | ✗ | ✗ | ✗ | ✗ |
| (n=14) | CM | 52 | 8 | Cerebellar atrophy | 6 | ✗ | ✗ | ✗ | ✗ |
| | CV | 59 | 8 | Cerebellar atrophy | 4 | | ✗ | ✗ | ✗ |
| | DC | 25 | 13 | Cerebellar atrophy | 22 | ✗ | | | |
| | DM | 25 | 13 | Cerebellar atrophy | 9 | | ✗ | ✗ | ✗ |
| | FM | 52 | 5 | Cerebellar atrophy | 8 | ✗ | | | |
| | MA | 34 | 9 | Cerebellar atrophy | 13 | ✗ | | | |
| | NR | 39 | 13 | Cerebellar atrophy | 9 | ✗ | | | |
| | PG | 55 | 5 | Cerebellar atrophy | 3 | ✗ | ✗ | ✗ | ✗ |
| | PS | 31 | 8 | Cerebellar atrophy | 8 | | ✗ | ✗ | ✗ |
| | PV | 21 | 13 | Cerebellar atrophy | 25 | ✗ | | | |
| | RM | 39 | 8 | Cerebellar atrophy | 7 | ✗ | | | |
| | RS | 27 | 8 | Cerebellar atrophy | 8 | ✗ | | | |
| | SL | 60 | 5 | Cerebellar atrophy | 7 | | ✗ | ✗ | ✗ |

Crosses indicate tests undertaken.
AICA, anterior inferior cerebellar artery; Benton, Benton line orientation test; DAT, differential aptitude test; Educ, education; ICA, idiopathic cerebellar ataxia; LCB, focal cerebellar lesions on the left side; MIN, Minnesota paper form board test; PICA, posterior inferior cerebellar artery; RCB, focal cerebellar lesions on the right side; SCA, superior cerebellar artery; WAIS, Wechsler adult intelligence scale.

Control groups were organised differently in the different experiments. As controls were age and education matched with the patients with cerebellar damage, we used three different control groups for the WAIS data, one for each experimental group ($C1_L$ for LCB, $C1_R$ for RCB, and $C1_A$ for ICA). Control data for the spatial experiments were collected by testing 10 subjects without a history of neurological or psychiatric illness, recruited from the patients' relatives or from volunteers (C2). Mean age and education of all the control groups are given in table 2. One way analysis of variance (ANOVA) did not show any significant difference in age or education between the controls and the patients in any experiment.

**Table 2** Age and education in the control groups

| Group | n | Age (years) | Education (years) |
|---|---|---|---|
| $C1_L$ | 12 | 43.5 (15.5) | 10.9 (2.8) |
| $C1_R$ | 9 | 45.6 (14.3) | 10.2 (3.5) |
| $C1_A$ | 10 | 34.6 (11.9) | 10.5 (2.6) |
| C2 | 10 | 43.1 (10.2) | 12.9 (0.3) |

Values are mean (SD).
$C1_A$, control group for patients with idiopathic cerebellar ataxia; $C1_L$, control group for patients with left focal cerebellar lesions; $C1_R$, control group for patients with right focal cerebellar lesions; C2, control group for the spatial experiments.

## WAIS-R

The numbers of subjects and controls doing this test were: LCB, 12; RCB, 9; ICA, 10; $C1_L$, 12; $C1_R$, 9; $C1_A$, 10. The revised version of the test for the Italian language[22] was used.

## Benton line orientation test

The numbers taking this test were: LCB, 10; RCB, 5; ICA, 7; C2, 10. The test employed was derived from that of Benton and colleagues.[23] This test is based on the presentation of lines with different orientations that have matched lines with identical slopes in a ''sun ray'' configuration of lines. Thirty stimuli preceded by five training stimuli were given. Only the 1.9 cm distal segments of one of the 3.8 cm long multiple choice lines were used as stimuli.

## Minnesota paper form board test revised

The numbers taking this test were: LCB, 9; RCB, 5; ICA, 7; C2, 10. The test was given following the guidelines of Likert and Quasha.[24] The stimuli consist of bidimensional cartoons that have to be assembled to match one of five simultaneously presented figurines. The subject has to indicate the figurine that can be formed precisely by assembling the stimuli. Bidimensional mental rotation is required to match the

cartoons with one of the figurines. The cut off time for the whole series of 60 items is 20 minutes.

### Differential aptitude test—spatial relations

The numbers taking this test were: LCB, 8; RCB, 5; ICA, 7; C2, 10. This test was taken from the three dimensional space test of the general aptitude test battery.[25] It requires three dimensional mental folding. Cartoons of unfolded cubes are presented. The subject has to choose the correct three dimensional solution from four perspective drawings of cubes. Forty items are presented and each stimulus has to be correctly matched with one or more of the five solution figurines. A maximum of 30 minutes is given for this test.

## Data analysis

Performances on each of the three tests were evaluated according to the authors' instructions. In particular, on *Benton's test* the number of errors and their distribution according to the slope of the stimulus were considered. In the *revised Minnesota paper form board test* the following variables were considered: the absolute number of correct answers; the test score (computed, following the authors' indications, as the total number of correct responses minus 1/5 of the incorrect ones[24]); the percentage of correct answers in relation to the number of stimuli processed; and the amount of the test completed. In the *differential aptitude test*, we evaluated the following variables: the number of correct answers; the number of errors; the percentage of items processed; the ratio between errors and correct answers (E/C); the percentage of correct answers in relation to the number of items processed; and the error score (ES) computed according to the formula:

$$ES = [\text{total errors} \times 100]/[\text{items processed} \times 5]$$

where 5 is the number of possible solutions presented per item.

Note that in this test each item can have more that one correct answer and thus errors and correct answers are not reciprocal.

The results were analysed statistically by using one way or two way ANOVA. When appropriate, post hoc comparisons were made with Duncan's test.

# RESULTS

## WAIS-R

Mean IQ scores and performance subtest scores are given in table 3. A one way ANOVA showed significant differences among the groups for full scale IQ ($F_{5,56} = 6.36$; $p<0.0001$), performance IQ ($F_{5,56} = 8.04$; $p<0.0001$), and verbal IQ ($F_{5,56} = 3.85$; $p<0.005$). A post hoc comparison indicated that the LCB group differed from the $C1_L$ for all IQ values. The ICA mean values, which were at the lowest level, differed significantly from the $C1_A$ data only for full scale and performance IQs. No significant difference emerged between the RCB and $C1_R$ IQ values. All groups of patients had impairments in different subtests of the WAIS-R (data not shown) in line with the pattern of cognitive impairment reported in subjects with cerebellar damage.[10 11] To achieve the aims of the present paper, we specifically focused on the visuospatial subtests of the WAIS-R (table 3). A one way ANOVA revealed significant differences among the groups for digit symbol ($F_{5,56} = 6.22$; $p<0.0005$), picture completion ($F_{5,56} = 6.33$; $p<0.0005$), picture arrangement ($F_{5,56} = 8.09$; $p<0.0001$), and object assembly ($F_{5,56} = 5.85$; $p<0.0005$). A post hoc comparison indicated that picture arrangement was highly affected in all groups of patients with cerebellar damage. Furthermore, differences from control performance were evidenced in the digit symbol subtest for the RCB and ICA groups; in picture completion for the ICA and LCB groups; and in object assembly for the ICA group. Block design was unaffected by cerebellar damage.

## Benton line orientation test

The patients with cerebellar damage tended to perform quite efficiently, with only slightly more errors than the controls (fig 1A). As expected, all subjects had some difficulty in identifying the lines furthest from the vertical or horizontal planes (lines 3, 8, and 9), as can be observed in fig 1B. ANOVA failed to reveal any difference among groups in scoring or in the distribution of errors according to the slope of the stimuli.

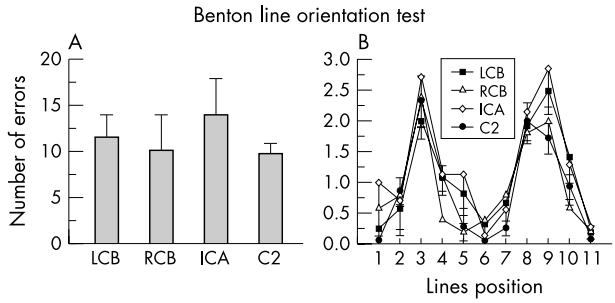


**Figure 1** Benton line orientation test. (A) Mean values of errors in the experimental groups with cerebellar damage and in the healthy controls. (B) Mean values of errors in the experimental groups with cerebellar damage and in the healthy controls distributed according to the slope of the stimulus. ICA, idiopathic cerebellar ataxia; LCB, focal left cerebellar lesion; RCB, focal right cerebellar lesion; C2, control group. Error bars = SD.

**Table 3** Mean scores of intelligence quotient and Wechsler adult intelligence scale, revised (WAIS-R) performance subtests in patients with cerebellar lesions and control subjects

| Subtests and IQ | $C1_L$ | LCB | | $C1_R$ | RCB | | $C1_A$ | ICA | |
|---|---|---|---|---|---|---|---|---|---|
| Verbal IQ | 110 (8.5) | 98.0 (10.8) | * | 106.8 (11.9) | 99.8 (15.2) | | 99.0 (10,9) | 89.4 (14.4) | |
| Performance IQ | 107.4 (8.2) | 95.0 (10.3) | * | 105.1 (9.9) | 98.1 (16.8) | | 106.8 (8.5) | 80.5 (14.3) | * |
| Full scale IQ | 109.4 (7.3) | 96.5 (9.7) | * | 106.3 (10.8) | 98.1 (15.3) | | 102.5 (9.8) | 84.5 (14.1) | * |
| Digit symbol | 8.4 (2.5) | 6.7 (2) | | 9.1 (2.8) | 6.0 (3) | * | 10.0 (2.5) | 4.5 (2.5) | * |
| Picture completion | 11.8 (1.6) | 8.7 (2.2) | * | 10.8 (1.8) | 9.6 (2) | | 11.3 (1.8) | 8.5 (1.2) | * |
| Picture arrangement | 10.3 (0.7) | 7.7 (2.5) | * | 9.8 (1) | 7.4 (2.9) | * | 11.1 (1.3) | 6.4 (2.9) | * |
| Block design | 8.7 (2.4) | 8.7 (2.6) | | 7.6 (2.6) | 8.5 (4) | | 8.8 (2.3) | 6.1 (2.5) | |
| Object assembly | 9.3 (2) | 7.4 (2.9) | | 9.3 (2.2) | 7.3 (2) | | 10.6 (2.5) | 5.4 (2.6) | * |

*$p<0.005$.
$C1_A$, control group for patients with idiopathic cerebellar ataxia; $C1_L$, control group for patients with left focal cerebellar lesions; $C1_R$, control group for patients with right focal cerebellar lesions; ICA, idiopathic cerebellar ataxia; IQ, intelligence quotient; LCB, focal cerebellar lesions on the left side; RCB, focal cerebellar lesions on the right side.

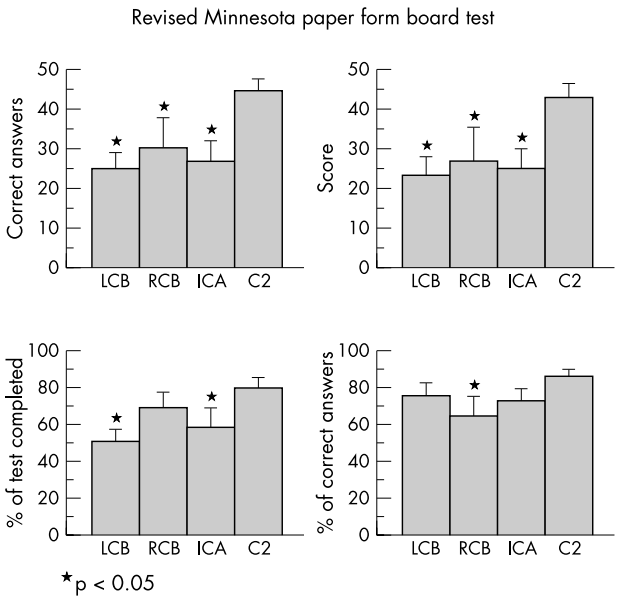


**Figure 2** Revised Minnesota paper form board test. ICA, idiopathic cerebellar ataxia; LCB, focal left cerebellar lesion; RCB, focal right cerebellar lesion; C2, control group. Error bars = SD.

## Minnesota paper form board test

A one way ANOVA showed significant group differences for number of correct answers ($F_{3,26} = 4.74$; $p = 0.009$) and for test score ($F_{3,26} = 4.56$; $p = 0.01$). In a post hoc analysis, all cerebellar groups scored significantly lower than controls (fig 2A). Group differences were observed in the percentage of the test completed (one way ANOVA $F_{3,26} = 4.27$; $p = 0.01$). A post hoc comparison indicated that only the LCB subjects completed significantly less of the test than the controls (fig 2C). Regarding the percentage of correct answers, a one way ANOVA did not reveal any significant differences among groups. When the C2 data were compared singly with any of the patient groups, only the RCB group was significantly different (one way ANOVA, $F_{1,13} = 5.87$, $p = 0.03$; fig 2D).

## Differential aptitude test

When required to reconstruct three dimensional figures mentally, patients in all three cerebellar groups were impaired. Differences among groups were observed when different test parameters were examined. The LCB and ICA groups had a low level of correct answers, but the RCB group was the only one with a large number of errors. All three groups had lower scores than the controls for error score, E/C ratio, and percentage of correct answers.

With respect to the number of correct answers, a one way ANOVA showed significant group differences ($F_{3,25} = 10.68$, $p = 0.0001$; fig 3A), while post hoc analysis indicated that only LCB and ICA results were significantly worse than C2 results. The situation was reversed when the total number of errors was considered: although a one way ANOVA failed to reach significance, in individual comparisons the RCB results were significantly worse than the C2 results (one way ANOVA, $F_{1,13} = 6.75$, $p = 0.022$). The reason for this puzzling result may lie in the amount of the test completed by the different groups. The LCB and ICA patients tended to complete about 60% of the items, while the RCB and C2 subjects answered about 95% of the items. A one way ANOVA showed significant differences among the groups in the percentage of the test completed ($F_{3,25} = 6.28$, $p = 0.0025$).

Post hoc comparisons confirmed that the LCB and ICA results were worse than the C2 results, and that the difference between the LCB and RCB data was also significant (fig 3C). When the number of errors was computed by considering the numbers of items processed—as in the error score—all groups of patients with cerebellar damage were significantly different from controls (fig 3D). The error score was about 30 for all the patient groups, while it was about 20 for the controls. A one way ANOVA failed to reveal any significant group difference, probably because of the similarity of the data among the cerebellar groups. However, one way ANOVA comparing the C2 data with any of the patient groups showed significant differences (LCB *v* C2, $F_{1,15} = 7.85$, $p = 0.013$; RCB *v* C2, $F_{1,13} = 4.62$, $p = 0.050$; ICA *v* C2, $F_{1,15} = 8.79$, $p = 0.010$). A similar trend was observed with respect to the E/C ratio and the percentage of correct answers. One way ANOVA comparing the C2 data with any of the patient groups showed significant differences as follows: E/C ratio: LCB *v* C2, $F_{1,15} = 6.99$, $p = 0.018$; RCB *v* C2, $F_{1,13} = 6.07$, $p = 0.028$; ICA *v* C2, $F_{1,15} = 4.94$, $p = 0.041$;

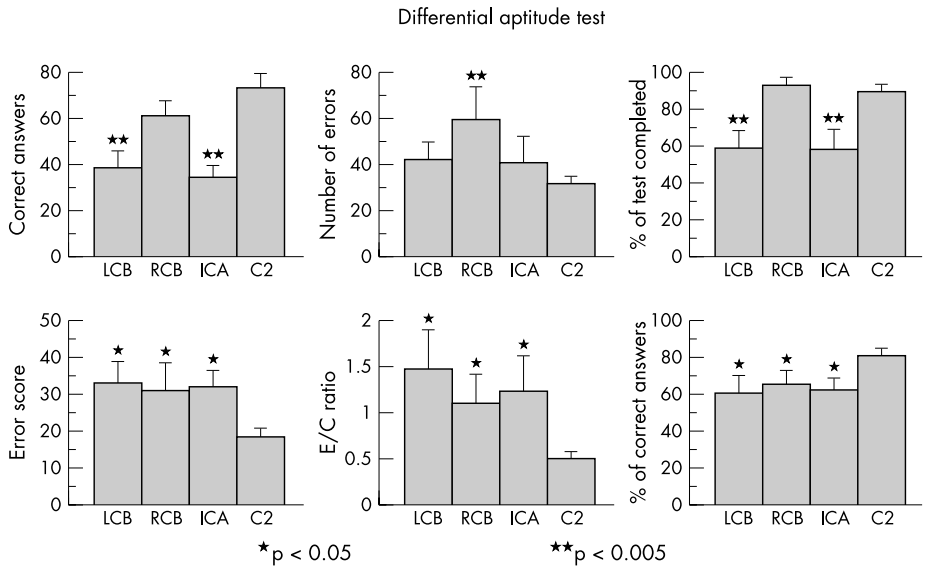


**Figure 3** Differential aptitude test. ICA, idiopathic cerebellar ataxia; LCB, focal left cerebellar lesion; RCB, focal right cerebellar lesion; C2, control group. Error bars = SD.

percentage of correct answers: LCB *v* C2, $F_{1,15} = 5.80$, $p = 0.029$; RCB *v* C2, $F_{1,13} = 5.59$, $p = 0.034$; ICA *v* C2, $F_{1,15} = 8.81$, $p = 0.0095$ (fig 3).

## DISCUSSION

These data show that a cerebellar lesion can induce impairment of visuospatial abilities with different characteristics depending on the side of the lesion.

In agreement with previous findings, the WAIS data indicate that cerebellar patients present a variety of deficits, particularly in subsets exploring decision making, reasoning, and performance.[3 26] Regarding the so called performance subtests, cerebellar patients are more impaired in the picture completion and picture arrangement tests than in the block design and object assembly spatial tests. These findings are similar to those reported previously.[10 26]

In the Benton line orientation test—a test of sensory analysis and elementary perception[27]—the performance of all groups of patients with cerebellar damage was similar to that of the controls. Also, the error distribution according to stimulus orientation was similar in all the groups (fig 2B). The close similarity in the performances of the controls and the different groups with cerebellar pathology indicates on the one hand a good ability to process monodimensional spatial information, and on the other, that basic visuoperceptual abilities are preserved. Fink *et al* reported that left cerebellar activation in the landmark task (line bisection) was strictly related to right parietal cortex activation.[5] This finding was interpreted as evidence of cerebellar involvement in the cognitive demands of the task. The present data do not directly support this hypothesis. In a single case study, Botez-Marquard *et al* reported impairment of the line bisection test two weeks after a left superior cerebellar artery stroke that was not present when the patient was retested two years later.[28] In the present study, most subjects presented with chronic cerebellar damage or were suffering from progressive chronic degeneration of the cerebellar circuits. In both cases, some compensation may have taken place, thus masking the possible contribution of the cerebellum to the monodimensional spatial judgement required by the line orientation test. Furthermore, functional MRI data have recently shown that line orientation is associated with clear bilateral activation of the parietal cortex.[29] Thus line orientation is not a lateralised function and—at least for subjects with unilateral lesions—one cerebellar hemisphere may compensate for the damaged contralateral one. On the other hand, as response and speed of processing time were not evaluated in the present study, it cannot be ruled out that a cerebellar lesion affects line bisection performance by slowing data processing without altering the precision of line judgement.

Clear visuospatial deficits are observed when cerebellar subjects are asked to process complex figures mentally, as in the MIN test. In this test condition, all cerebellar groups performed more poorly than controls. In particular, both the number of correct answers and the MIN score were impaired. These parameters did not differ significantly among the three groups of cerebellar patients. Nevertheless, patients with right cerebellar lesions tended to have slightly better performances than those with atrophy or left sided lesions. Group differences emerged when the number of items processed was taken into account. Patients with right sided lesions tended to complete the test, while those with left sided lesions processed only about 50% of the test items, and patients with atrophy fell in between. Although the absolute number of correct answers was similar in the two groups with focal lesions (fig 2A), if the number of correct answers is related to the amount of the test completed (fig 2D), only patients with right sided lesions were significantly impaired. Thus, although patients with left and right cerebellar lesions were impaired in solving the task, they had specific deficits. Subjects with left sided lesions processed fewer items, but rather correctly, while subjects with right sided lesions processed more items but with a low level of precision.

It is interesting to note that in the block design subtest of the WAIS-R, which is very similar to the MIN, all groups of cerebellar patients had good performance, similar to that of the controls (table 3). This apparently conflicting evidence can be interpreted in the following way. Although an abstract figure is used as the stimulus in both tests, and the solution requires rotating the stimuli, the block design test can be solved by direct manipulation of the parts, while the MIN test can be solved only by mentally rotating the parts. Also, in the block design, subjects are required to match each block directly with the solution figurine, while in the MIN test, direct comparison is impossible. In the latter test, subjects have to assemble the stimuli mentally and then compare the mentally assembled figure with five possible solutions. These data suggest that cerebellar damage may affect the ability to undertake visuospatial manipulations mentally. This hypothesis is supported by evidence of cerebellar activation during the mental rotation of objects.[30] The cerebellar activation observed is bilateral, with a right prevalence. This asymmetry of cerebellar activation might explain the differences found between patients with right and left cerebellar damage. In fact, a lesion of the right hemicerebellum—where greater activation is reported—is associated with a lower level of correctness on the MIN test.

Also, in the DAT test the solution can be reached by mental folding and manipulation of the stimuli followed by mental matching with the possible solutions. In the MIN test, the stimuli must be reconstructed in three dimensions, and this is particularly difficult for patients with cerebellar damage. Error score, E/C ratio, and the percentage of correct answers indicated that all groups of subjects with cerebellar damage were highly impaired.

According to our analyses, the characteristics of the cerebellar lesion—that is, lesion side and aetiology—did not seem to influence performance level. The effect of the lesion side can be seen by analysing the number of items processed and the response correctness. These analyses showed differences in performance between patients with right sided and left sided cerebellar damage. Patients with right cerebellar lesions completed all the test items, while patients with left sided lesions were able to process only a few of the items. In the DAT test, but not in the MIN test, both right and left sided groups had a low level of correctness. Performance of the ICA group fell in between, but more closely resembled the group with left sided cerebellar damage. It is interesting to note that in both the MIN and the DAT tests, independent of the spatial requirements of mental rotation in two or three dimensions patients with right sided cerebellar damage behaved differently from those with left sided damage. Subjects with left cerebellar damage consistently processed only a few items. On the other hand, subjects with right cerebellar damage had impaired correctness on both the MIN and the DAT tests, while subjects with left sided damage were impaired only on the more demanding task (the DAT test).

Spatial processing is generally considered to be a distributed function sustained by a complex network of cortical and subcortical structures.[31 32] From anatomical evidence that cerebellar modules are topographically connected to discrete cortical areas,[33 34] and recent theories of cerebellar functioning indicating its distinct facilitation over cortical processing,[35] we suggest that a lesion of a given cerebellar module alters the activity of the connected cortical domains. Thus subjects with different cerebellar lesions can present quite different spatial syndromes.

Although more studies are needed to determine whether further parcelling occurs, the comparison between subjects with right and left sided damage is in line with this interpretation.

On clinical grounds our findings show that cerebellar disorders are not purely associated with motor symptoms but have significant effects on cognitive ability, including visuospatial skills, which might required specific rehabilitation approaches. It is well known that spatial impairment affects motor rehabilitation, and specific treatment of spatial impairment can improve functional recovery.[3 36]

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